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Design of a hydro-electric power
plant on salt River, Arizona

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**DESIGN OF A HYDRO-ELECTRIC POWER
PLANT ON SALT RIVER, ARIZONA**

BY

JOSEPH ROBBINS

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOSEPH ROBBINS

ENTITLED DESIGN OF A HYDRO-ELECTRIC POWER PLANT ON SALT RIVER,

ARIZONA

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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DESCRIPTION OF DAM ON SALT RIVER.

Salt River Valley lies south of the central part of Arizona, and contains by far the largest irrigated area in that Territory. Part of its water supply is obtained from the Salt River, forming below the confluence of Verde River, the largest stream in Arizona.

There is quite a large territory in Arizona which has not sufficient water for farming, and for this reason the Salt River storage reservoir was built. The power plant is a secondary consideration and could never have been built if it were not that the expensive dam is already there. The dam is 217 feet above low water, but only during very great floods would the water ever flow over the crest. The two spillways, one on each side of the dam, will carry all the water under ordinary flow. The spillways are eight feet below the dam crest. By using two hundred feet of pipe to take the water from the dam to the power house an effective head of 180 feet may be used as a conservative estimate of the effective head on the machines. The spillways are 20 feet deep and are excavated in the solid rock sides of the canyon. The structure is built on a circular curve, convex upstream, the back having a radius of 400 feet and the face a shorter radius from the same center.

The windows of the power house are to be 10 feet above the bed of the river, and the tailrace will be provided with a gate by which, if it ever becomes necessary, backwater from the

discharge of the spillways can be prevented from entering the power house. At such times, perhaps once in twenty or thirty years, it may become necessary to close down the plant for a few hours

OBJECT OF THIS PLANT AND NATURE OF THE LOAD.

The cost of coal in Globe the nearest point to the dam site is \$10.00 a ton, and the cost of haulage is \$10.00 more. This makes a total of \$20.00 a ton. A power plant using coal as a fuel would be wholly out of the question under these circumstances. A hydro-electric power plant seems the only feasible solution of the cheap power question for the industrial development of the vicinity. Abundant natural cement deposits are found within a radius of two and a half miles of the site of the power plant. The object of this plant is to utilize the waste power of the dam and to develop the cement industry. The scarce population near the dam would not be sufficient to make such an installation as contemplated, pay if the lighting load was depended upon to utilize all the power. It might be possible to sell all the power available in Goldfield and Mesa City. This would necessitate a 45 mile transmission line and incur a large expense. Greater profit would result from cement mills. The load will be practically full load for 10 hours of the day. The lighting load at night will be insignificant. Two 2300 volt three phase lines go out from the station in opposite directions. Two mills are on each of these lines and the voltage is transformed down to 220 volts.

GENERAL CHARACTERISTICS OF HIGH AND LOW HEAD WATER POWER PLANTS.

In modern practice there are two general types of water

wheels, the pressure turbine and the impulse water wheel. The pressure turbine is used where a large quantity of water at a low head is available. The impulse wheel is used where a high head and a small quantity of water is available. The limiting height is about 50 feet although no marked line is drawn. The tendency is to use pressure turbines of special design for higher heads when very great amounts of power are to be developed and the quantity of water used is large. An example of this is at Niagara where pressure turbines are used in 5000 H. P. units for a 160 foot head. In the same plant Pelton wheels are used in small units for pumping purposes. The most striking example of the use of pressure turbines is in the Feather River development in California where a maximum head of 525 feet is used in 20,000 H. P. units. In this case the turbines are of the vertical shaft, inward flow, Francis type running at 400 R. P. M. For small units such as are used in the Salt River plant, impulse wheels will be preferable. Pelton wheels were chosen. This is essentially a high head wheel relying on the impulsive force of the water on moving vanes, rather than the constant and uniform pressure of a large, slow-moving mass of water. It consists of a cast iron or steel center, to the periphery of which are attached cups or buckets. The high efficiency of the Pelton wheel is largely due to the design of the buckets. These receive the stream at a tangent to the periphery of the wheel, absorb the force of power and discharge the water at practically no velocity and at a slight angle, so as to avoid interference with the succeeding bucket.

DATA REQUIRED FOR ESTIMATES.

The data required for estimates of a power plant are:

(1) The amount of water available in cubic feet per minute. (2.) The head or vertical fall from ditch flume or other source of supply, to the point where the wheel is to be located. (3.) Length of pipe necessary to obtain the given head. (4.) Horse-power required--maximum and minimum--and the character of machinery to be driven.

SELECTION OF MACHINERY.

Some lighting load is to be carried so 25 cycles can not be used. If direct current were used the loss due to the large current and low voltage would be excessive. This necessitates 60 cycle alternating current. Since the load is almost entirely motor load and about two miles away, three phase 2300 volt transmission will be best. There are two principal makes of impulse wheels, Pelton and Abner Doble. Both the works are at San Francisco. Pelton wheels were selected for this plant. One extra generator is used for safety.

CALCULATIONS.

Some of these values are taken from the Pelton catalog.

Given 180 feet effective head.

Spouting velocity = 6455 feet per minute.

Use three 500 K. W. or five 250 K. W. generators to carry the 1,000 K. W. load. The price will determine which.

For 60 cycles,--

$$n = \frac{60 \times 60 \times 2}{\text{R. P. M.}} = \frac{7200}{\text{R. P. M.}} \quad \text{where } n \text{ is the number}$$

of poles on the generator.

From the tables the speeds for standard sizes of wheels are given.

Foot Wheel	R. P. M.	H. P. for 1 wheel	Cu. ft. per Min.	No. Poles on gen.
2	513	18.1	62.49	14
4	256	72.41	249.97	28
6	171	16.3	562.96	42

Forty-two poles is too many and 18.1 H. P. per wheel will necessitate too many water wheels on one shaft to obtain the required power, so the four foot wheel is best, the generator having 28 poles and a speed of 256 R. P. M.

$$1000 \text{ K. W.} = 1340 \text{ H. P.} = \text{Gen. H. P. required}$$

$$50 \text{ K. W.} = \frac{67 \text{ H. P.}}{1407 \text{ H. P.}} = \frac{\text{Exciter H. P. required}}{\text{H. P. required for both.}}$$

The efficiency of the generators will be 91 per cent.

$$\frac{1340}{.91} = 1470 \text{ H. P. required from Pelton for the}$$

generators.

$$\frac{67}{.91} = 73.5 \text{ H. P. required from Pelton for one exciter.}$$

H. P. of a one inch stream of 180 ft. head = 10.19.

$$\frac{73.5}{10.19} = 7.21 = \text{"Constant" found in tables.}$$

Nearest constant from table = 7.29 which gives 2.7 inch stream for exciter. Use 15 inch wheel with speed of 820 R. P. M.

Price of three 500 K. W. generators equals

$$3(11 \times 500 + \frac{216000}{256}) = \$19035.$$

Price of five 250 K. W. generators equals

$$5(11 \times 250 + \frac{216000}{256}) = \$17975 \text{ where the price per}$$

generator including exciter is found from formula:

$$11 \times \text{K. W.} + \frac{216000}{\text{R. P. M.}} = \text{Cost.}$$

Use five 250 K. W. generators and two 50 K. W. exciters which are run by Pelton wheels. Four of these generators and one exciter are run for full load.

$$\frac{1470}{8} = 184 \text{ H. P. per wheel when using eight single wheels.}$$

$$\frac{184}{10.19} = 18.1 = \text{"Constant"}$$

From tables nearest constant is 18.49 which gives a stream of 4.3 inches per nozzle for the generators. Use a double nozzle wheel for each generator.

For 4.3 inch nozzle a 9 inch pipe is large enough.

For 2.7 inch nozzle a 9 inch pipe is also used.

Where two pipes join to make one large one the cross section of the large one which is $\frac{\pi}{4} \times (\text{diameter})^2$ must equal the sum of the areas of the two smaller ones for the same velocity. Two 6 inch pipes = One 9 inch pipe.

SWITCH BOARD.

There are seven panels to the switch board, five generator panels, one exciter panel and one panel for the two outgoing lines. On the last panel at the right end of the board is a

bracket on which are the synchronizer and voltmeter which records the voltage for one phase only. This bracket is at right angles to the board so the instruments are visible from any other panel. The synchronizer bus, exciter bus and generator bus runs the length of the board. The object of the line voltmeter is to see that the station output is always up to voltage. This voltmeter has a light behind it and is clearly visible from a long distance.

The three phase voltmeter switch is a device to save the cost of three voltmeters for every generator panel.

The station is lighted from the exciter; connections are made to the field bus. The leads go to a small switch cabinet on the wall which governs the different circuits. Just inside the wall of the plant is an alluminum cell lighting arrester. Form K G.E. oil switches are used. They are closed by hand and opened electrically in case of an overload on the lines. The switch board is of solid marble two inches thick, and held by iron angle bars which are fastened to the wall. Potential transformers are placed overhead, behind the switch-board. All wires from machines to board are laid in conduits under the floor.

PELTON WHEEL SPEED REGULATION.

One double nozzle wheel is attached to each generator. The speed of the Pelton wheel is kept constant as the load varies by means of the Pelton Oil Pressure governor. This is done automatically by deflecting the stream of water away from the buckets. As the machines are being brought up to synchronous speed the automatic governor is cut out and a D.C. Motor which is governed

at the switch board deflects the nozzle. After the machine is running in parallel the D. C. Motor switch at the board is opened and the pressure governor is cut in by means of a clutch on the governor.

The exciter is of Westinghouse make and is rated at 75 H. P., 56.25 K. W., 125 volts, 450 amperes, 800 R. P. M. This is run between 800 and 820 R. P. M. The voltage of the exciter is regulated by a Tirrel regulator.

SIZE OF PIPES TO GENERATOR AND EXCITER PELTONS.

35.18 Cu. ft. per min. = Flow through 1 inch nozzle for 180 ft. effective head.

(4.3) x 35.18 = 652 Cu. ft. per min. = 10.85 Cu. ft. per second for one nozzle.

No. nozzles.	Quantity Cu. :ft. per sec.	Size of :Pipe In.	Velocity :ft. per sec.	Length of :Pipe--ft.	Friction :Lost-ft.
1	10.85	9	24.5	4	1.1
2	21.7	16	15.5	16	.985
4	43.4	24	13.8	30	.98
6	65.2	30	13.2	30	.717
8	86.8	36	12.3	200	3.44
1 Ex.	4.35	9	9.85	22	.975

Sample Calculation for head lost in friction in pipe follows:

$$H = \frac{f l v^2}{d 2g} \quad \text{where } f \text{ is a constant, } l \text{ is the length of}$$

pipe in ft., d is the inside diameter of the pipe in ft., v is the velocity of the water, g is a constant due to gravity.

For 16 inch pipe 16 ft. long for 2 nozzles:

$$H = \frac{.022 \times 16 \times (15.5)^2}{1 \frac{1}{3} \times 2 \times 32.2} = .985 \text{ ft.}$$

Maximum friction loss from intake to nozzle of generator Pelton =

$$1.1 + .985 + .98 + 3.44 = 6.505 \text{ ft.}$$

There is ten feet of head available for losses due to bends, valves and friction and still have 180 ft. effective head. This leaves 3.495 ft. for bends and valves and they will come within this limit.

DESCRIPTION OF LAY-OUT OF PLANT.

The water supply for this plant is brought in one wrought iron riveted pipe, which is three feet in diameter, from a little above the dam. About thirty feet outside the building the pipe diverges into two pipes, and these distribute the water as shown in floor plan diagram. The pipes are laid just underneath the floor. The tailrace is ten feet deep and is simply a concrete lined canal covered with slate slabs. The outlet is at the end of the station. The side of the plant nearest the dam has no windows but those on the other side and ends are nine feet high and arched at the top. The walls are of concrete blocks and are fifteen feet high. A gable roof is covered with tile and is supported with iron beams. There is no crane.

Line #100

Line #200

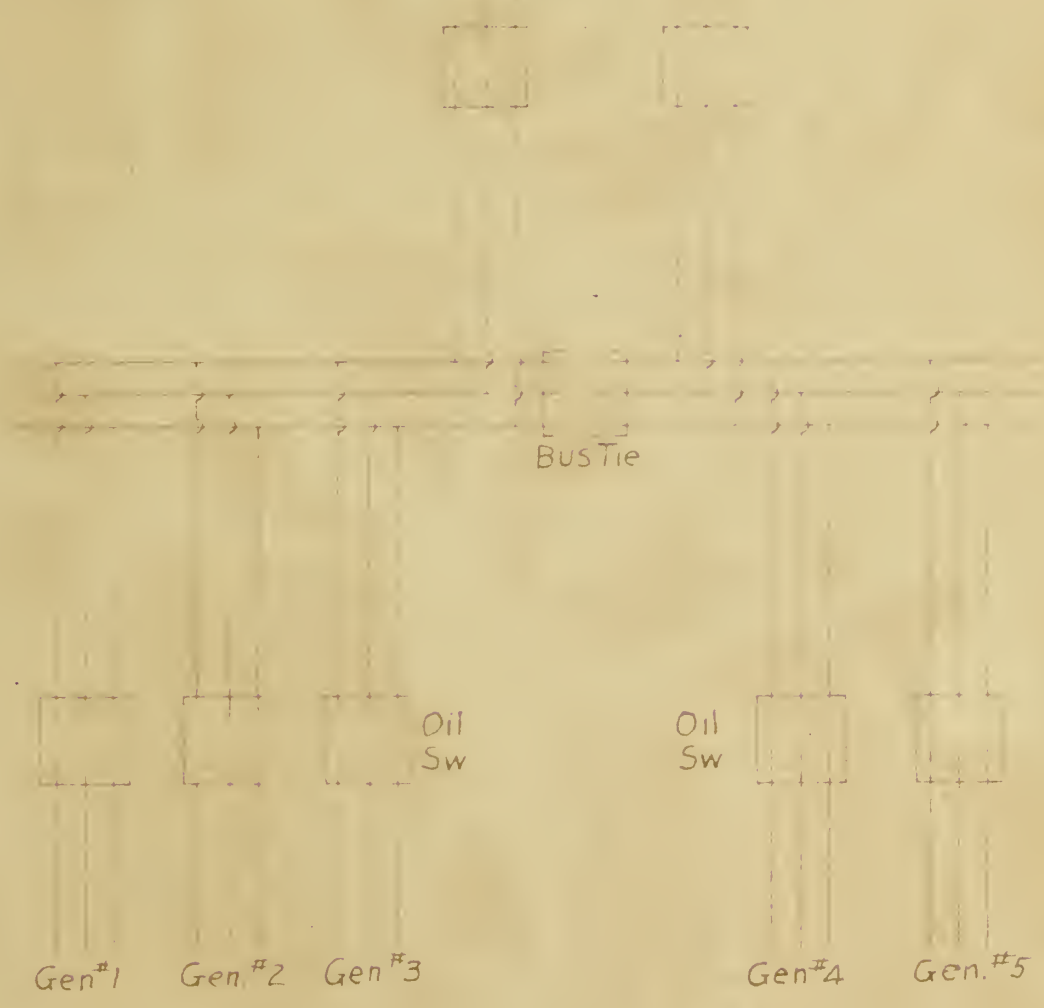
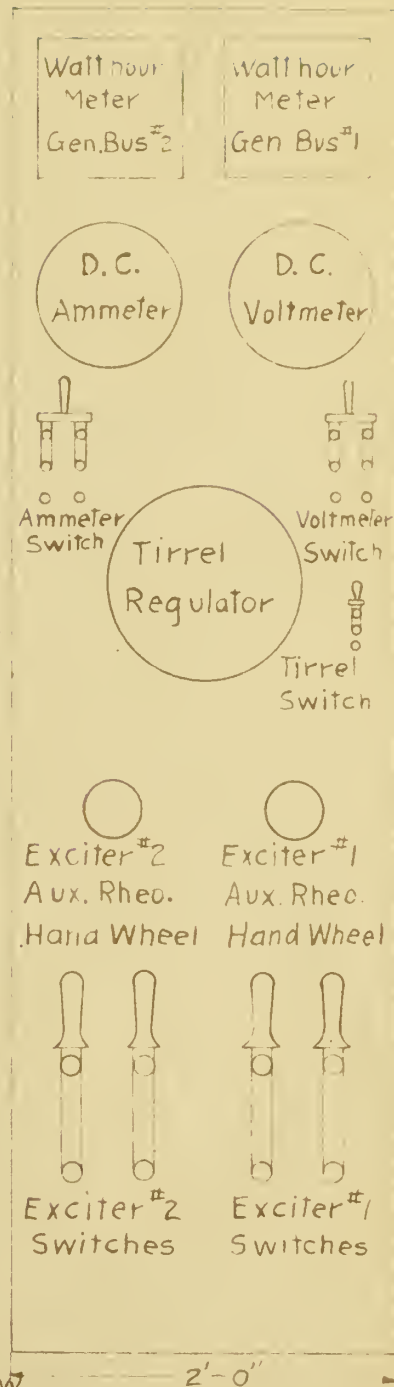
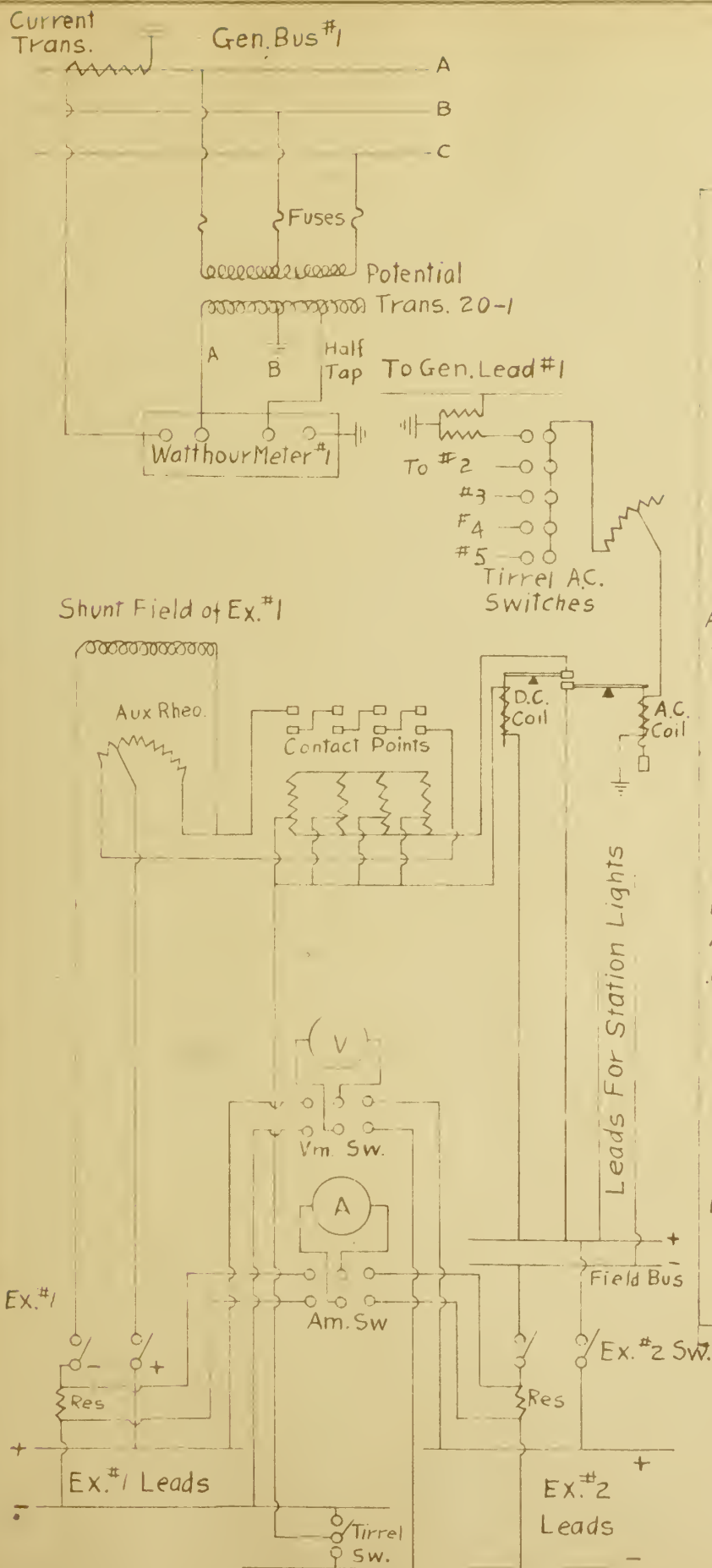
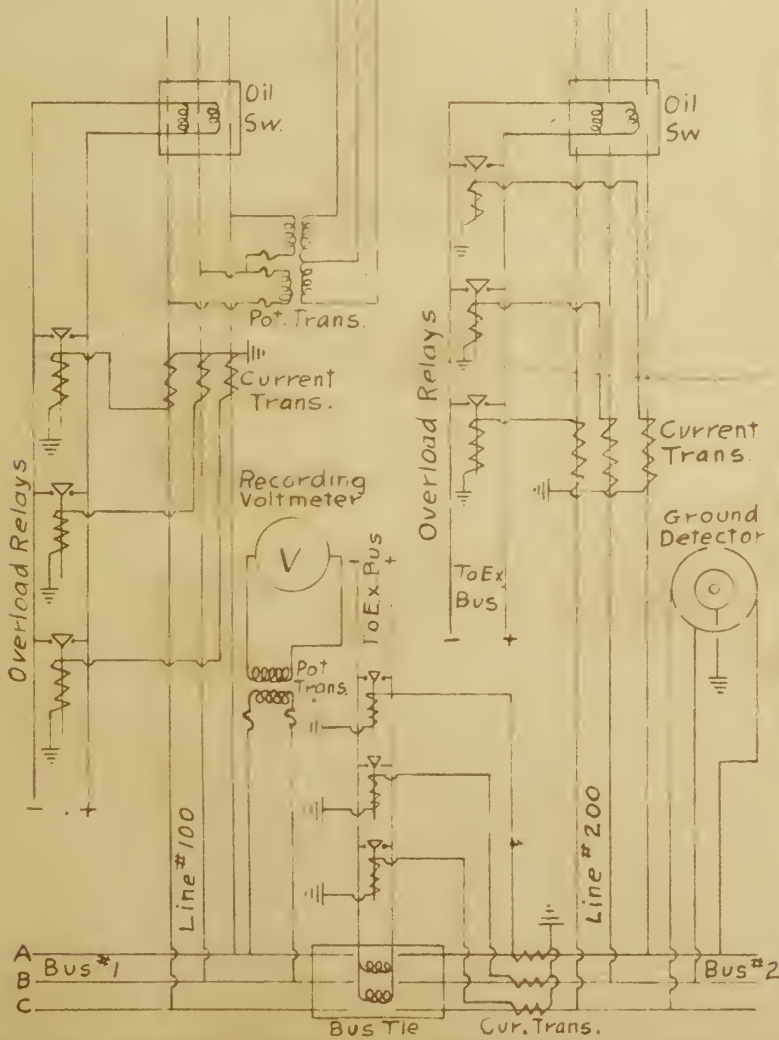
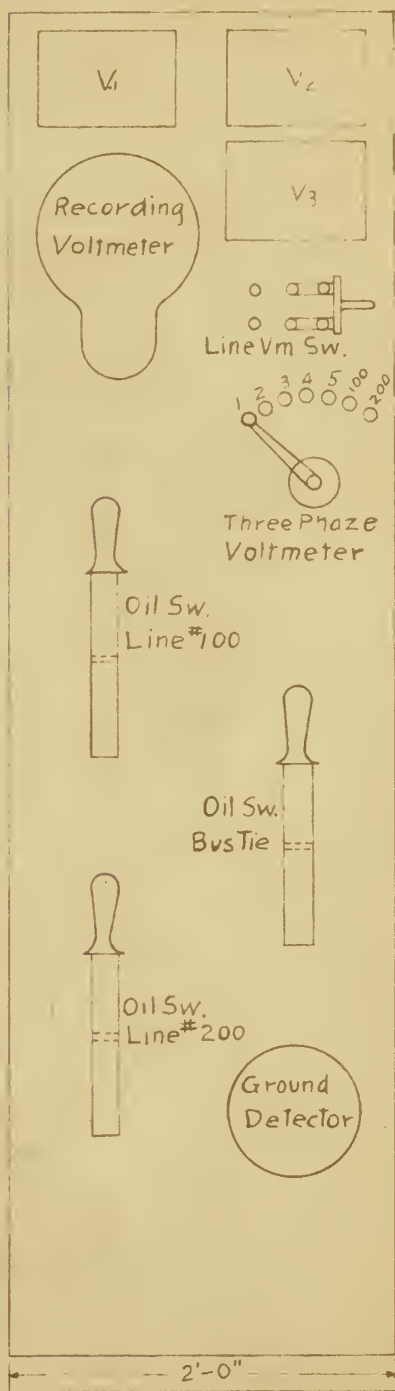
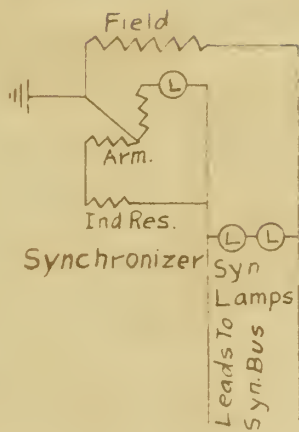
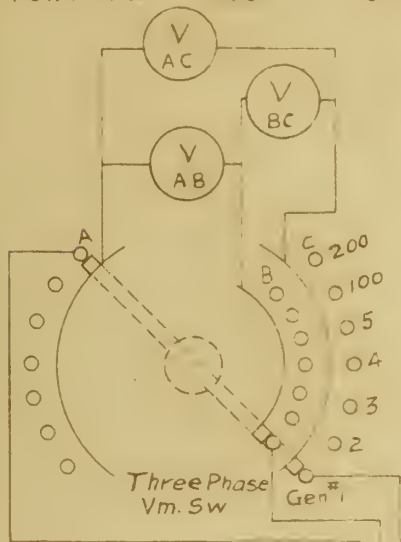
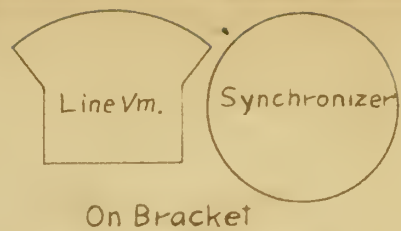
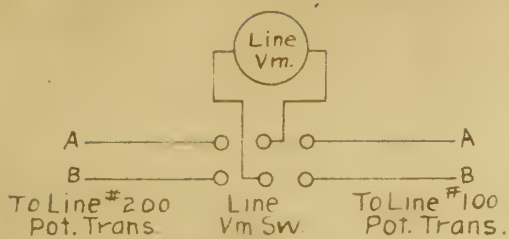


DIAGRAM OF
CONNECTIONS
OF
BUSES.



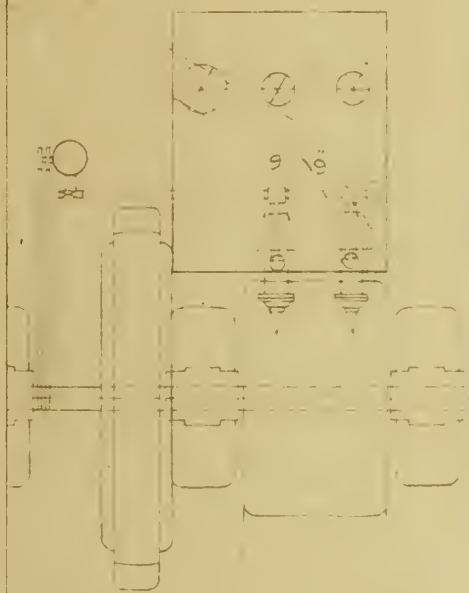
EXCITER PANEL AND CONNECTIONS. THERE IS ONE OF THESE.

Scale: $\frac{1}{12}$ Size.



OUTGOING LINES PANEL
ON RIGHT END OF BOARD.
ALSO INSTRUMENTS ON
RIGHT END OF THIS PANEL.
Scale: $\frac{1}{12}$ Size

Tried to find 20" pipes the joined



Tail Race

Switch Board

4-0"

10'-0"

HYDRO-ELECTRIC PLANT





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